Conceptual Methods for Change Inventory and Monitoring of Vegetation Resources

Version 2.0

Prepared for
Jon Vivian, *RPF*
Resources Inventory Branch
Ministry of Forests
P.O.Box 9516 Stn Prov Govt
Victoria, BC V8W 9C2

Project: MFI-401-055

December 13, 1999

J.S. Thrower & Associates Ltd. *Consulting Foresters*
Vancouver - Kamloops - Victoria, BC

106-04941/

Executive Summary

The Ministry of Forests has proposed to add a fixed-area plot configuration and sampling method to the Vegetation Resources Inventory (VRI) system. These additional tools provide more options to inventory and monitor change over time in timber and non-timber attributes. These tools can be used over an inventory area in conjunction with or independently of the five-point plot cluster currently used in the VRI. This system can be applied at the provincial-level and in smaller forest management units such as Timber Supply Areas and Tree Farm Licenses. Implementation of this system over the province would provide data to meet the National Forest Inventory goals and could supplement estimates in management units; however, provincial-level sampling would be independent of management unit sampling. Data from implementing the system in management units could be used to meet certification requirements, track changes in non-timber vegetation cover, and monitor projections of change in the timber attributes.

Table of Contents

1. INTRODUCTION 1

1.1 Terms of Reference 1
1.2 Background 1
1.3 Project Objectives 1

2. THE VRI SYSTEM 3

2.1 A Variety of Methods in the VRI 3
2.2 Designing a VRI-Based Inventory or Monitoring System 3

3. PROVINCIAL CHANGE INVENTORY 5

3.1 Goal 5
3.2 Rationale 5
3.3 Target Population 6
3.4 Sample Location Selection 6
3.5 Ground Plot Design 7
3.6 Sample Size 8
3.7 Measurement Schedule 8
3.8 Estimating Change 9
3.9 Potential Use of the Information 9

4. MANAGEMENT UNIT CHANGE INVENTORY AND MONITORING 10

4.1 change inventory 10
4.2 Monitoring Change in Timber Attributes 11

5. APPENDIX I - DEFINITIONS 16

6. APPENDIX II - YEAR 2 PROJECT TASKS 17

7. APPENDIX III - NATIONAL FOREST INVENTORY 18

8. APPENDIX IV - REVIEW OF MONITORING PROTOCOLS USED IN THE US 20

9. APPENDIX IV - SUMMARY OF THE ERP COMMENTS 22

List of Tables

Table 1. VRI sample cluster components 3
Table 2. Proposed number and distribution of provincial plots 8
Table 3. List of attributes (measured or derived) 14

List of Figures

Figure 1. Proposed sample plot configuration for estimating change 7

1. INTRODUCTION

1.1 Terms of Reference

This discussion paper was prepared for the Ministry of Forests (MOF), Resources Inventory Branch by J.S. Thrower & Associates Ltd. Our team included: Ian Cameron *MF, RPF,* Eleanor McWilliams *MSc, RPF,* A.Y. Omule *PhD, RPF,* Guillaume Thérien *PhD,* Jim Thrower *PhD, RPF, and* Bill Warren *PhD.* This report version 2.0 incorporates the comments (Appendix IV) from the Expert Review Panel (ERP) and Mike Bonnor *PhD,* on an earlier version of the report. The ERP included: John Barker *PhD, RPF,* Jim Flewelling *PhD,* Kim Iles *PhD,* Peter Marshall *PhD, RPF,* and Don Munro *PhD, RPF.*

1.2 Background

This is year 2 of a contract awarded to us in 1998 by the MOF to develop growth and yield monitoring protocols focusing on: 1) Volume and Decay; 2) Forest level Growth; 3) Treatment Response; 4) Forest level Yield; 5) Early Stand Development; and 6) Provincial-level Monitoring [National Forest Inventory (NFI) in BC]. The MOF Growth and Yield Monitoring Task Force (GYMTF) reviewed the 1999 reports[1] and accepted some recommendations including those pertaining to monitoring tree volume, decay and waste, and monitoring treated stands (Treatment Response). The GYMTF requested that further work be done on developing protocols for early and late forest growth monitoring and provincial level monitoring.

1.3 Project Objectives

The MOF has now directed us to shift focus and view growth and yield monitoring as a component of change inventory and monitoring and to develop ground-sampling methods (sample location selection and plot design) to provide change data for timber and non-timber attributes at the provincial- and management-unit levels. The ground-sampling methods would be part of the Vegetation Resources Inventory (VRI) (Section 2).The purposes of the change data are:

1. National reporting of the Criteria and Indicators (C&I) of sustainable forest management by Ecozone, and other NFI goals (Canadian Forest Service, CFS).

[1] These reports include: Adjusting tree volume, decay and waste estimates in British Columbia; Monitoring growth and yield using VRI sample plots: Version 2.0; Stand growth estimation literature review; Monitoring growth and yield of treated stands; and Monitoring early stand development.

2. Provincial reporting of vegetation (forest) resources status and change (MOF Annual Report).
3. Management-unit tracking of vegetation change for purposes such as certification.
4. Management-unit checking (monitoring)[2] of projections of timber volume and other tree attributes (e.g., species composition and top height) used in timber supply analysis.

[2] See Appendix I for definitions.

2. THE VRI SYSTEM

2.1 A Variety of Methods in the VRI

The VRI is a system of sampling methods, procedures and standards for sampling tree and other forest vegetation in BC. Conceptually, the VRI is a toolbox containing a variety of methods to design an inventory to meet different needs. To date, the VRI has focused on methods to estimate and audit current timber resources and abundance of non-timber resources using a five-point plot cluster. These clusters include a central sample point (the integrated plot center (IPC)) surrounded by four auxiliary points located (typically) 50 m at cardinal directions from the IPC. Several types of plots are referenced to the IPC to estimate current vegetation attributes (Table 1).

The sampling methods discussed in this report using a fixed-area plot (400 m^2) (Table 1) should be considered as new tools in the VRI system. The MOF has added these new tools to give practitioners more options to meet objectives that require re-measured plot data and data on non-timber attributes. We expect that the VRI will continue to change over time as current procedures are refined, new methods are added to system, and some are replaced or discontinued. However, changes should be minor and not affect the ability to compare successive measurements.

Table 1. VRI sample cluster components.

Resource	Sampling Unit	No. Units
Trees		
Large Trees (≥4 cm)	Variable radius	5
	or 400 m^2 (NEW)	1
Small Tree (<4 cm)	19.6 m^2	1
Site Trees	100 m^2	5
Ecology		
Shrubs (foliar cover intercept)	Line intercept (24 m)	2
Shrubs (height, % cover)	314 m^2	1
	or 400 m^2 (NEW)	1
Herbs, mosses, & tree seedlings	100 m^2	1
Succession	1962.5 m^2	1
Soil	Soil pit	1
Coarse Woody Debris	Line intersect (24 m)	2
Range (forbs, graminoids)	0.5 m^2	4

2.2 Designing a VRI-Based Inventory or Monitoring System

There is no single best inventory or monitoring method for all situations. The appropriate mix of sampling systems and methods to use in an inventory or monitoring system depends on many factors. For example, common factors to consider include objectives of the

inventory, available funds, the opportunity cost of investing in one plot system over another, personal comfort of the forest manager with different options, current politics, legislation, and the special features of the landbase. Some VRI-based inventories may include only the original VRI plot clusters, the new fixed-area plots, or a combination of both. Each combination of plot types will have it's own cost, benefit, and potential use.

The VRI system provides sampling methods to meet provincial-level and management unit sampling objectives (Section 1.3) as follows:

1. Estimate provincial change and yield to provide data for national and provincial reporting (purposes 1 and 2, Section 1.3).
   Proposed new inventory methods - CFI using modified VRI integrated plot. The modification consists of replacing the prism plot for large trees with a fixed-area 400 m^2 (11.28-m radius) plot. Plots would be established using either the CFS stratified sampling approach or equal probability selection (Section 3). These estimates are based on a representative sample and do not need additional monitoring.

2. Estimate management unit yield.
   Use current VRI methods - the five-point prism cluster. These estimates are based on a representative sample and do not need monitoring.

3. Track changes in resources over time for purposes such as certification.
   Two proposed new options (Section 4.1):
   i) re-measure plots established to estimate management unit yield.
   ii) establish new independent plots and re-measure to estimate and monitor (check) change.

4. Audit management unit yield projections obtained from GY models (e.g. VDYP7)
   Use current VRI methods - the inventory audit procedures.

5. Monitor (check) management unit change projections obtained from models.
   Two proposed options (Section 4.2):
   i) re-measure VRI plots established to estimate management unit yields combined with periodic independent yield audits.
   ii) establish independent re-measured fixed-area plots that are representative of the management unit.
   Both approaches allow estimates of initial conditions in the management unit and the model projections to be evaluated.

3. PROVINCIAL CHANGE INVENTORY

3.1 GOAL

The goal of the provincial-level sampling is to:

> *Estimate changes and trends over time of timber and non-timber attributes to meet provincial and national level reporting needs (Section 1.3).*

The timber and non-timber attributes of interest are those defined by the VRI and include all NFI attributes (Appendix III).

3.2 RATIONALE

Existing provincial resources inventory practices cannot provide timely and accurate information about the extent, state, and sustainability of Canada's forest resources with the necessary country-wide consistency. Furthermore, the existing inventory methods are weak in non-timber values and any assessment of changes and trends. However, Canada needs inventory data to assess progress toward sustainable forest management, to support policy development, national and international inquiries, and for reporting on climate change (e.g., Kyoto Protocol).

In cooperation with the provinces and territories, the CFS has developed a new plot-based NFI core design to address national needs. The new NFI design consists of photo plots and ground plots, located on a 20-km grid (Appendix III). The new design is sufficiently flexible to allow BC or other provincial and territorial governments to cost-effectively integrate the design into existing or planned inventories.[3] This section outlines proposed modifications to the NFI core design (ground plots only[4]) for integration into BC's VRI system.

---

[3] Canadian Forest Service. A plot-based national forest inventory design for Canada. An interagency partnership project. CFS, Victoria, BC (contact: Mark Gillis); also personal communication with Mark Gillis and Steen Magnussen, CFS.

[4] The NFI photo plots are aimed mainly to capture information on forest landuse and land classification area changes; they are not discussed further in this report. The ground plots capture information on timber volumes and abundance of non-timber resources, attributes not easily measurable from photo plots.

3.3 Target Population

The target population is the entire area of BC, including Vegetated and Non-Vegetated (BC Landcover Classification Scheme, BCLCS) areas. This area is approximately 95.2 million ha.

3.4 Sample Location Selection

3.4.1 Stratified sampling approach (CFS)

We considered two approaches for locating sampling points: stratified sampling recommended for the NFI (CFS) and an alternative equal probability sampling using the VRI. The CFS proposes to stratify and report population by Terrestrial Ecozone, as defined by the NFI. This method selects ground samples at random from photo points on a 20-km grid stratified by Ecozone. The random selection in strata is achieved by assigning each photo point a random number, sorting the list of the photo points by the random number, and including the first 314 ground sampling points that fall on land as the sample. Sample points on water or permanent non-vegetated areas (e.g., urban areas) would be tracked separately. If samples land on the edge of a water body, the proportion of the area covered by water would be determined and mapped.

The advantage of this approach is that the stratification may provide good provincial estimates by ecozone. The disadvantages are that the stratification may lead to future complexity in analysis and documentation as strata definitions and boundaries change over time, and likely misuse of the data in the future through improper weighting.

3.4.2 Equal probability sampling approach

This is a CFI approach that samples the landbase over time using a set of ground sample points across the province selected with equal probability. The points could be selected systematically. One possibility is to use a list sorted by Ecozone and land type (BCLCS). The systematic sample could be selected in three batches; each distributed over the entire population. The selection in batches provides another option for variance estimation from the systematic sample. Post-stratification can be done to provide estimates by Ecozone

The advantages of this approach are that it eliminates problems created by stratification, and the systematic selection ensures all areas are represented appropriately by their proportionate area. The

disadvantage is that good estimates may not be obtained for all Ecozones.

3.4.3 Recommendation

We recommend the equal probability alternative as the main objective is to obtain provincial-level statistics. The NFI goals would be achieved by combining the BC sample with those from other provinces to obtain national statistics by ecozone.

3.5 Ground Plot Design

3.5.1 Configuration

We considered two plot design: the proposed CFS design[5] and the VRI. These designs are similar in configuration; the main difference is plot sizes.

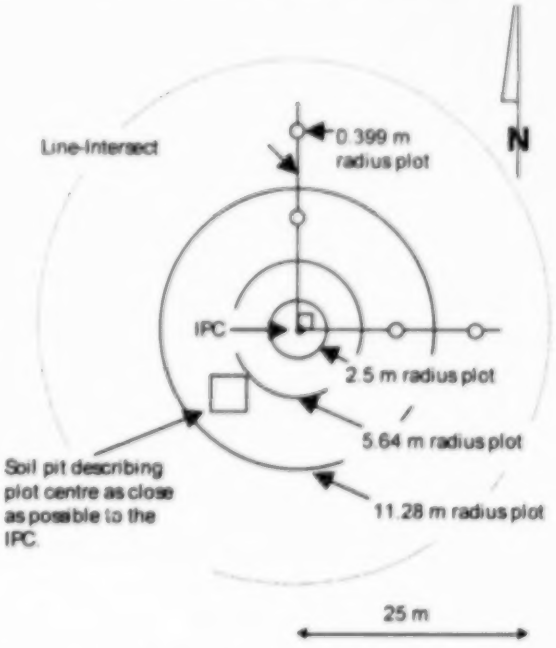

Figure 1. Proposed sample plot configuration for estimating change.

We recommend the VRI set of plots (with the prism plot replaced by a fixed-area (11.28-m radius plot) as required by the MOF) because field procedures and experienced crew are already available for the VRI. This set of plots from the VRI system is centered on a single point (no auxiliary plots) and includes four concentric circular plots, line intercepts, and a soil pit (Figure 1).

3.5.2 Attributes to Measure

These sample plots provide data on four main components of the land and vegetation - ecology, trees, coarse woody debris, and range (Table 1) for the NFI (Appendix III). Data definitions, standards, measurements, field cards could be based on the VRI Ground Sampling Procedures manual, including the new plot configuration. Usual forest or other management activities should not be prohibited or altered at these sampling locations. That is, the plots should be "hidden" and re-locatable. The intent is that all trees would be re-locatable (stem mapped, not tagged) such that diameter and height growth on each tree would be known.

---

[5] Canadian Forest Service. *The National Forest Inventory Ground Sampling Plot - Design, Standards and Procedures.* Draft 3, August 1999.

3.6 Sample Size

The CFS (with advice from the MOF) recommended a minimum of 314 ground sample points selected at random from the 2,367 photo locations (approximately 1 in 8) distributed over the province (on land) on the national 20-km grid, with a minimum of 50 plots/stratum (Table 2). This ground plot sample size should, however, be investigated relative to cost and variability of change estimates using simulation studies. With the recommended equal-probability-sampling alternative, the approximate sample distribution among the CFS-defined strata and sample size is shown in Table 2. The scope of inference of the 314 samples is the 2,367 photo locations from which the samples are selected (finite population sampling theory). The 2,367 photo locations, in turn, are a systematic sample of the BC land area (target population).

The effect of abandoning strata minimums is negligible in BC since the Taiga Plains and the Boreal Plains (with less than 50 sampling points) constitute only a small proportion of the land base. The number of sampling points in water would be in proportion to area of the landbase classified as water (BCLCS).

Table 2. Proposed number and distribution of provincial plots.

Terrestrial Ecozone[a]	Area (%)	CFS[b] Photo locations	CFS Ground Sample Points	JST[c] Ground Sample Points
Montane Cordillera	47.3	1,119	112	149
Pacific Maritime	21.7	513	52	68
Boreal Cordillera	19.8	469	50	62
Taiga Plains	6.9	164	50	22
Boreal Plains	4.3	102	50	14
Total	*100*	*2,367*	*314*	*314*

[a] Ecological Stratification Working Group. 1995. *A National Ecological Framework for Canada*. Agriculture and Agri-Food Canada, Ottawa/Hull. Report and national map at 1:7,500,000.

[b] Number of intersection of the national 20-km grid.

[c] Approximate, as we propose equal probability sampling.

3.7 Measurement Schedule

We endorse the CFI approach proposed by the CFS of a rotating panel of sample points measured periodically (5-20 years).[6] This is different from the traditional periodic inventory where all plots are measured in a given time period. Assuming a 5-year cycle, a panel of 1/5 of all sampling units (approximately 60 sample clusters) would be re-measured every year. Panels could be formed

[6] The inventory and growth monitoring protocols in the United States are adopting similar methods (Appendix IV).

from a systematic selection of plots (e.g., from a list sorted by age). All clusters would be established and measured in the first year at the same time. A sub-set of plots (e.g., 10%) would be designated for measurement each year to facilitate periodic update of plots to a common year.[7]

The main advantages of the rotating-panel approach (compared to the traditional CFI where all plots are measured in a given time) are that the information is current, especially for areas where rate of change is high, and re-measurement costs are distributed over a period of years. (The benefits of annual measurement of a subset of plots and of the rotating panel approach should be investigated, especially if the cycle is short, e.g. 5 years.) The main disadvantage is that the estimates of change may be less precise than the traditional periodic inventory and may fluctuate annually.[8] Methods to improve the precision of the estimates (e.g., Kalman filter[9]) should be investigated.

3.8 Estimating Change

The required attributes are re-measured and the estimates on each current occasion are made. The differences between the estimates made on the two occasions are compiled, and appropriate statistics (means, totals and changes, and variances) for the attributes are calculated where possible. There are various ways to calculate the current occasion statistics including moving averages using only current measurements.[10]

3.9 Potential Use of the Information

The collected data would be summarized and submitted to CFS to meet the NFI goals, including the reporting of the C&I for Canada. The summaries would also be used to produce a provincial table of areas, tree attribute statistics, and coarse woody debris volumes possibly by BCLCS land-type (Vegetated Treed, Vegetated Non-Treed, and Non-Vegetated), for the MOF Annual report. The ground plots would be re-

---

[7] Scott, C.T., M. Kohl, and H.J. Schnellbacher. 1999. A comparison of periodic and annual forest surveys. For Sci. 45 (3):433-451.

[8] Gillespie, A.J.R. 1998. Pros and Cons of Continuous Forest Inventory: Customer perspectives. Paper presented at the *Integrated Tools for Natural Resources Inventories in the 21st Century* conference, August 16-19, Boise, Idaho, US.

[9] The Kalman filter takes into account the relationship between successive values of the population mean (e.g. Dixon, B.L. and R.E. Howitt. 1979. Continuous forest inventory using a linear filter, Forest Sci. 25(4):675-689.)

[10] Scott, et al. ibid.

locatable and could potentially be revisited to collect information for other initiatives such as national reporting for the Kyoto protocols or other uses.

4. MANAGEMENT UNIT CHANGE INVENTORY AND MONITORING

4.1 CHANGE INVENTORY

4.1.1 Objectives

Sampling to estimate change in timber and non-timber attributes at the provincial level is not of sufficient resolution to meet management unit needs. There are several possible reasons to track change in vegetation attributes in a management unit including to:

1. *Meet certification requirements* - by external agencies such as the Forest Stewardship Council, and to demonstrate that certain targets are met (e.g., abundance of plant diversity, coarse woody debris volumes, lichen loading and herb/shrub biomass).
2. *Track non-timber vegetation cover* - to detect changes in presence or proportion of plant species as an early warning indicator of climatic or other changes.
3. *Develop a database of change information* - that could be queried to address other timber supply and forest management questions. For example, the database could provide an overall picture of forest dynamics, such as incidence of insect/disease infestations over time. However, the change database should not be used as a substitute for studies specifically designed to meet these other objectives.
4. *Monitor projections of change in timber attributes* (Section 4.2).

4.1.2 Sampling Method

The sampling approach for change inventory should depend on the management unit objectives. For example, to achieve objectives 1 to 4 above, change data could be obtained from remeasured VRI plots. Where a VRI based on the five-point cluster of prism plots has been implemented, a portion of these plots could be used to estimate the change in selected attributes (primarily timber based).[11] Where a VRI is not in place, samples to estimate change could be taken using VRI

[11] *Monitoring growth and yield using VRI sample plots: Version 2.0*, contract report prepared for the MOF by J.S. Thrower & Assoc.

methods with clusters including the new fixed-area plot, the current prism-plot clusters, or a combination of both.

Design details must depend on the objectives and considerations of specific management units. They should also consider potential statistical issues that may arise from mixing original VRI cluster plots with a single-point set of fixed-area plots, and the need to roll up the management inventories to a Timber Supply Area (TSA) or the Provincial level. In any case, however, the objectives should be clear, target population well defined, a representative sample taken, and the population and sample properly documented. As an example, in the next section we discuss monitoring change projections of timber attributes for timber supply analysis; objectives 1-3 are not discussed any further.

4.2 Monitoring Change in Timber Attributes

4.2.1 Objective

The objective is an independent check on the projected growth or change in timber attributes over a management unit to provide a level-of-comfort on the accuracy of the change projections used in timber supply analysis. Observed change would be compared to predicted change (using initial inventory estimates and model projections). Difference between actual and predicted change can raise "red flags" where differences are large. Sensitivity analyses in the application of growth and yield information in timber supply analysis can help define the attributes that need monitoring.

4.2.2 Target Population

The population for change monitoring should be the Vegetated Treed areas likely to contribute to timber supply in a management unit such as a Tree Farm License (TFL) or a TSA. According to the BCLCS, this includes all areas with at least 10% crown cover of tree species of any size, excluding non-productive and non-forest areas. Users may change this definition, however, population boundaries should preferably not change over time.[12]

4.2.3 Sub-units

For the same reasons stated in Section 3.4.2, we do not recommend stratifying management units. However, there may be a need in some area to increase sampling intensity in sub-units such as a group of

---

[12] Small increases in the population could be accommodated by proportionately adding samples to the new areas of the original population.

watersheds that form part of a special project, or a group of treated stands from a specific management period. These sub-unit boundaries should be spatial (landscape), not change over time, and should be well defined and documented. More sampling points could be located in these sub-units for a one-time sample (yield audit) or with the intent of re-measurement. However, these additional samples should be weighted differently when combined with the core-monitoring sample. They would receive less weight than would be suggested by their number, to account for differences in sample sizes.

Creating sub-units should be avoided or kept to a minimum. This is to reduce problems related to subdividing a population before sampling, including mapping errors, increased documentation costs, and increased complexity in sample selection, re-measurement, and analysis.

4.2.4 Sample location selection

4.2.4.1 Option 1 - Re-measured VRI plots

We considered two approaches for selecting samples for change monitoring: re-measure VRI plots or installing an independent set of re-measured plots. Re-measuring VRI plots involves two processes: 1) re-measuring a subset of the VRI sample to check the ability of growth models to track change in timber attributes from *given* initial conditions, and 2) periodic checking of the initial conditions based on an independent audit sample. The audit sample is needed because it is possible that while relative change may be accurate, the initial conditions may not. The sub-set of plots could be randomly or purposively selected (preferred).

The advantage of this option is the potentially increased sampling efficiency by using previously established VRI samples. The disadvantage is that conclusions cannot be confirmed until both samples are done, unless it is planned to do the VRI plot re-measurement and the audit sample at the same time.

4.2.4.2 Option 2 - Independent re-measured plots

This approach involves checking change projections *independent* of the initial conditions in a management unit. This is achieved by establishing and re-measuring plots that are independent of the VRI plots used to determine initial conditions (yield). This same sample could also be used to check the initial yield from photo-interpreted data. The sample would be selected with equal probability within the population or sub-unit. Sample points could be selected systematically - with a random start - from a sorted list of all grid intersections

of the provincial 100 x 100-m grid (used in the VRI) in a target population.[13] This list could be sorted by land type (BCLCS), and Vegetated Treed points sorted by volume or expected yield. This sorting process helps ensure the sample is representative of the target as defined by the attributes in the sort list.

The advantage of this approach is that it consists of only one process that can be implemented independent of the basic VRI. The disadvantages are the usual sampling error associated with the sample at the initial time, and the introduction of independent program that management may not support (especially while the basic VRI is barely starting).

4.2.4.3 Recommendation

Both options appear reasonable and the choice of methods should depend on specific management unit considerations. For example, if a VRI already exists, Option 1 may be more plausible because of potential gains in efficiency. On the other hand, if the both the models and initial conditions are not independent of the VRI, Option 2 may be preferred.

4.2.5 Plot Design

4.2.5.1 Configuration

We considered two options for the plot design:

1. The set of plots suggested for the provincial sampling (Section 3), measuring only tree attributes and using the fixed-area plot (11.28 m radius) for large trees ($\geq$ 4 cm) instead of the prism, as determined by the MOF.
2. The VRI timber emphasis cluster that uses the prism sample-tree selection method for the large trees, as recommended by J.S. Thrower & Assoc.[14]

The MOF has mandated the fixed-area plot (Option 1). This option is well proven, field measurement and office analysis procedures are straightforward, may not be prone to frequent errors, may be give more precise estimates of change, and it is the best if mortality is of key interest. However, given today's computing power and developments in

---

[13] With the systematic sample, the sequencing of plots to measure should be well planned to avoid an incomplete sample if the project is terminated suddenly.

[14] *Monitoring growth and yield using VRI sample plots: Version 2.0*, contract report prepared for the MOF by J.S. Thrower & Assoc.

tree measurement techniques, use of Option 2 should be re-considered by the MOF. Application of Option 2 should be investigated and demonstrated as this nay be more efficient, especially where a VRI is in place.

4.2.5.2 Attributes to Measure

The main items of interest are yield (single-point-in-time from a sample) and net change (including mortality) of VRI tree attributes (Table 3). Data collection methods are described in detail in the VRI Ground Sampling Procedures manual. As in the provincial sampling, usual forest or other management activities should not be prohibited or altered at these sampling locations, i.e., plots should be "hidden" but re-locatable, and the trees stem mapped and not tagged.

Table 3. List of attributes (measured or derived).

Attribute	Estimate
Top Height (m)	Measured
Age of Top Height Trees (yr.)	Measured
Site Index (m)	Derived
Average Height (m)	Measured
Trees/ha (m)	Measured
Basal Area (m^2/ha) by species	Measured
5- & 10-year Basal Area growth (m^2/ha/yr)	Measured
Volume (m^3/ha)	Derived

4.2.6 Sample Size

The formal process to estimate sample size is to anticipate the results (e.g., target sampling error for volume change) and compute the sample size needed to achieve a given precision. We suggest an arbitrary minimum of 30 plot sets in a management unit. This sample size should be modified depending on budget, change variability, and desired precision in change estimates. The provincial plot sets could also be used to supplement the management unit sample.

4.2.7 Measurement Schedule

We propose a CFI approach based on the traditional periodic inventory where all plots are measured in a given time period (every 5-10 years); this is different from the provincial sampling where we propose a rotating panel. We suggest this approach because the number of samples in a management unit would typically be smaller (30-50) and management unit sampling may be staggered.

4.2.8 Check change projections.

Change could be checked by comparing the predicted change over a give period (e.g., change in basal area, top height, Lorey height, and species composition) to the observed changes from the monitoring

points.[15] This could be done in a manner similar to the current Inventory Audit program and answer the question: "How accurate, on the average, are the change predictions for a management unit?". The predictions would be combined with the monitoring estimates if in agreement. If not in agreement, the source of the discrepancy must be identified. The disagreement could, for example, be included in the Chief Forester's AAC rationale statements as impetus for further investigation if the disagreement has a significant impact on management decisions.[16]

The differences between observed and predicted values should be interpreted with caution. Large variation in both the observations and the predictions, and short-term fluctuations, could mask any real differences and long-term trends.[17] The monitoring information may also not be adequate to help modellers identify possible causes of model prediction biases.

---

[15] Yield could also be checked by comparing observed yield to a given time to the yield projected by growth models such as TIPSY and VDYP.

[16] Chris Fletcher and Tim Bogle (MOF Timber Supply Branch).

[17] Ken Mitchell, Don Reimer, Abdel-Azim Zumrawi, Phil Comeau, Rob Drummond, George Harper, and Balvinder Biring.

5. APPENDIX I - DEFINITIONS

We define the following terms for this report:

Change inventory is the process of observing changes and trends over time in the level of the resource and change in land cover classification between two or more time points.

Change projection is the process of predicting the difference in future level or classification of the resource between two or more time points in a management unit.

Change monitoring is an independent check on the projected change or growth in a management unit.

Growth monitoring is the process of observing the growth of a forest and comparing this with the predicted growth of that forest. Growth monitoring is a specific type of *change monitoring*.

Yield audit is the process of observing the yield of a forest and comparing this with the predicted yield of that forest.

6. APPENDIX II - YEAR 2 PROJECT TASKS

A. *Conceptual sampling methods* - Develop, discuss and recommend conceptual sampling methods to estimate and monitor change at the provincial and management unit levels.

B. *Detailed procedures* - Produce a more detailed report that includes estimators, procedures, standards and field protocols, based on conceptual methods approved by the GYMTF (Task A). Demonstrate the use and application of the recommended methods.

C. *Strategic sampling plan for pilot study* - Complete a strategic sampling plan for a pilot study of the change monitoring design at the provincial level, including the study objectives and desired products, and a general strategic direction for implementing the pilot project.

7. APPENDIX III - NATIONAL FOREST INVENTORY[18]

Background

The Canadian Council of Forest Ministers (CCFM) has committed to produce balanced, interpretive national-level reports on the status and trends of the Criteria and Indicators (C&I) of the CCFM and the Montreal Process. A new plot-based NFI has been developed in light of the CCFM commitment. The purpose of the NFI is to "…assess and monitor the extent, state and sustainable development of Canada's forests in a timely and accurate manner." The new system is designed to provide national data on status and trends on 25 forest resource attributes in support of the Criteria and Indicator processes (CCFM and Montreal Process), and to provide data for national and international initiatives (e.g., Climate change, FAO/ECE Forest Resource Assessments).

The NFI also provides a framework for collecting data on other criteria and indicators (e.g., socio-economic indicators), and for studying the factors affecting forest health and productivity.

Finally, the new design should be sufficiently flexible to allow the implementing agencies (provinces and territories) to integrate the design into existing or planned inventories in a cost-effective manner.

The new design is expected to be implemented over the next decade. The first report, with data collected according to the new design, is expected in 2005. The guiding principle in the development of the new plot-based NFI is that the resulting data from the inventory has to be nationally consistent. That is, the same attributes must be measured, using the same standards in a statistically defensible manner, at an acceptable level of precision. The NFI core design has the following essential elements:

- A network of permanent sampling points across Canada.
- Stratification of sample points (by terrestrial ecozone) with varying intensity among strata.
- Estimation of some attributes from remote sensing (photo plots) on a primary (large) sample.
- Estimation of wood volumes and other desired data from a (small) ground-based sub-sample.
- Estimation of changes from repeated measurements of all samples.

[18] Mark Gillis (Canadian Forest Service, Victoria), personal communication.

Design and implementation in Provinces and Territories can be flexible if guiding principle are met.

NFI Key Attributes

1. Total Forest Area
2. Area by Forest Type
3. Area of Cover Type by Age Class
4. Area of Forest Types by Protection Status
5. Area of Other Wooded land by Protection Status and [Forest] Type
6. Area of Age Classes by Protection Status
7. Area and % of Forest Land Managed Primarily for Protective Functions
8. Area of Regeneration and Afforestation by Type (of regeneration and afforestation)
9. Area of Surface Water in Forests (= forest land)
10. Area of Forests Undisturbed by Man
11. Area of Other Wooded Land Undisturbed by Man
12. Number of Forest Dependent Species
13. Number of Native and Exotic Species in Forests
14. Origin (local/non-local) of Seedlings in Regenerating Areas
15. Area Available for Timber Production
16. Area Converted to Non-forest Use
17. Area and Severity of Insect Attack
18. Area and Severity of Disease Infestation
19. Area and Severity of Fire Damage
20. Area of Forest Depletion (Harvest)
21. Area and % of Forest Land with Significant Soil Erosion
22. Total Biomass by Forest Type, Age, Succession Stage
23. Total Volume of all Species on Timber Productive Land
24. Area/volume of Plantations (native/exotic)
25. Current Volume Growth of Forest (gross, net)

8. APPENDIX IV - REVIEW OF MONITORING PROTOCOLS USED IN THE US

Overview

The US inventory and monitoring programs reviewed were the Forest Inventory and Analysis (FIA) started in 1930; the Forest health Monitoring (FHM) started in 1990; and the new Forest Inventory and Monitoring (FIM), which is an amalgamation of the FIA and some aspects of the FHM, to be implemented in 2000. These programs are similar in concept to what we have proposed for the BC provincial change detection.

Forest Inventory and Analysis

The FIA program was started in 1930. The objective was to provide a comprehensive inventory and analysis of present and prospective inventory of forest and rangelands in the US. The program was implemented as snapshot inventory state by state on 7-15 year intervals. The sampling design is grid-based, two-phased: Phase I - photo interpretation, and Phase II - ground sampling. Phase I consists of a grid of one grid point per 97 ha of forestland, and Phase 2 consists of one grid point per 2509 ha. The sampling consists of a cluster of plots of varying designs from region to region. Information from the FIA program is used for strategic level planning.

Forest Health Monitoring

The FHM program was initiated in 1990. The objective was to monitor, assess and report on status, changes, and trends in forest condition (health) in forest lands in the US. This information was to be used for strategic level planning, policy and program management needs at national, regional and state levels. The main activities of the program are: detection monitoring (ground plots and surveys), evaluation monitoring (most extensive activity) , and intensive site ecosystem monitoring (ISEM).

Detection monitoring (the plot component) consists of permanent plots on a 27-km grid on forested areas. To date there are about 4600 plots in 50 States where measurements are made annually (rotating panel). The measurements include: lichen communities, trees (damage, mortality, growth, regeneration, crown condition), plant diversity, and vegetation structure. This plot component is to be merged with FIA to form new FIM (amalgamation to be implemented 2000). The detection monitoring (survey component) is a survey of insect, disease, etc. measuring symptoms (defoliation, foliage discoloration, tree die back,

branch breakage, etc). The sampling uses a cluster of 5 plot locations at a sampling point (similar to the BC VRI). The detection data cover all forested lands and analyzed (to estimate annual change over short time (2-4 year) intervals) to determine if changes ands trends are within normal bounds, indicate improving conditions or are a cause for concern and warrant additional evaluation.

Evaluation monitoring examines extent, severity, and probable cause of undesirable changes/improvements in forest health beyond that in detection monitoring. It attempts to identify cause/effect relationships.

The ISEM activity is an in-depth monitoring of specific set of indicators at selected sites for a rigorous cause/effect relationship studies, identify key processes that shape forest ecosystems, etc.

Forest Inventory and Monitoring

The FIM program is a new program that integrates the FIA plots with Detection Monitoring Plot component of FHM program. The objectives are to provide forest inventory and forest health data. These data are intended to be used in strategic level inventory on all forestlands useful at state, region and national levels. The FHM program merges all the FIA and FHM (Plot component) into a three-phase sampling design, where the FHM detection plots will be Phase 3 of the FIA program. The three phases are: FIA: Phase I at one grid point per 97 ha of forestland; Phase 2 at 1 grid point per 2509 ha; and Phase 3 - FHM Plots at 1 per 64,640 ha. It is planned to conduct a continuous inventory involving lower intensity sampling simultaneously in all States every year (measurement of approximately 20% plots in each state). The new program is planned to be implemented in 2000.

9. APPENDIX IV - SUMMARY OF THE ERP COMMENTS

Overview

An earlier version of this discussion paper (dated November 30, 1999) was reviewed by the ERP and Mike Bonnor, *Ph.D.* In general, they cautiously supported our recommendations, did not see any major issues in the proposed conceptual sampling methods, questioned the need to introduce another fixed-area plot to the VRI, and provided suggestions for clarity of presentation. Their major comments are summarized below.

General

1. GY monitoring has always been considered part of VRI system.
2. Give source of definitions in the Appendix I.
3. "… Adding a different plot design to any existing inventory process should not be undertaken without a detailed and thorough consideration of all the potential ramifications to sample estimates and error calculations. Task "B" (Appendix 11 - Year 2 Project Tasks, Page 15), the production of a detailed procedures report, will be a critical step in the process. Developing statistical procedures to deal with future VRI inventories, which might include a mix of original VRI variable cluster plots with single point fixed plots may prove to be formidable. Elimination of pre-stratification is definitely a good first step…."
4. "… The concentric circle design of fixed plots is well proven and time honored. In fact, the Provincial inventory summaries of 1957 and 1967 were founded on plots of this design established from 1950 to 1956. A decision to retreat to a design used 50 years ago in a pre-computer era will no doubt be perceived by some professionals as a retrogressive step. Resources Inventory Branch would be well advised to prepare for such criticism…."
5. Do not use of the word "cluster" to describe what is actually a series of subsets at the same point; use the term "set" of fixed area plots.
6. On the introduction of another fixed-area plot, "… Is the fact that the MOF has determined a sufficient basis for acceptance of the fixed plot design?…" There is already a fixed-area plot for plants, why add another plot? Do not recommend fixed-area plot for timber.
7. "… The fixed-area plots have been mandated by MOF - which may be sufficient reason to use them; however, it would be appropriate to note that change computations from fixed-area plots, with numbered trees, are commonly used because the field procedures and

computational procedures are straightforward, and not prone to errors…."

8. It is OK to proceed with the provincial level sampling; however, for management unit sampling, we question the need to introduce at this time more complexity (change inventory/monitoring protocols) to an already complex system (the VRI). We should wait till the basic VRI is stabilized.

Provincial-level sampling

1. Measurement of a subset of plots every year would seem to be very expensive. What are the benefits?
2. A traditional CFI based on the 5-year re-measurement scheme would seem to provide excellent estimates of growth rate for the forest (average of observed 5-year growth rate).
3. Consider using a growth model (applied to the photo point data) as a covariate for more precise estimates of change.
4. Does stratification by ecozone significantly improve the mean estimate?
5. What ground procedures need to be followed to estimate mortality?
6. The samples that fall in water or permanently non-vegetated areas should be inspected to see if the classification is correct.

Management unit sampling

1. To eventually be able to roll up the management unit inventories within a TSA or the province, we should recommend that the VRI plot design be used, even if there is no VRI in place.
2. What is the basis of sample size 30? Consider cost and variability; the biggest problem with the VRI is cost.
3. For a systematic sample, there is a problem with sequencing and whether all plots get sampled. Need to be randomly sequenced in order of visit.
4. For the systematic selection from a sorted list, sort by volume or expected yield to stabilize growth.